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University of Munic

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Fabrication of Monolithic U-10Mo Fuel Foils for the Technical University of Munich

SIGMA Division

SIGMA-1 – Deformation Processing



Cody A. Miller

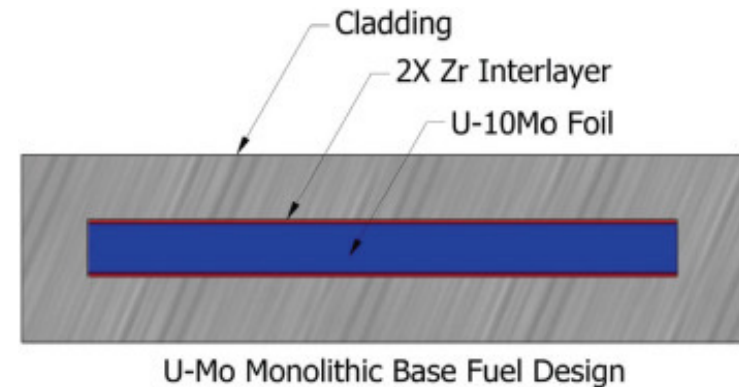
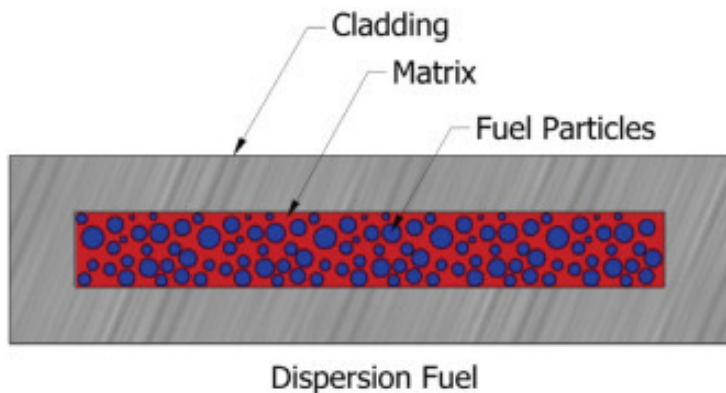
August 9-11, 2021



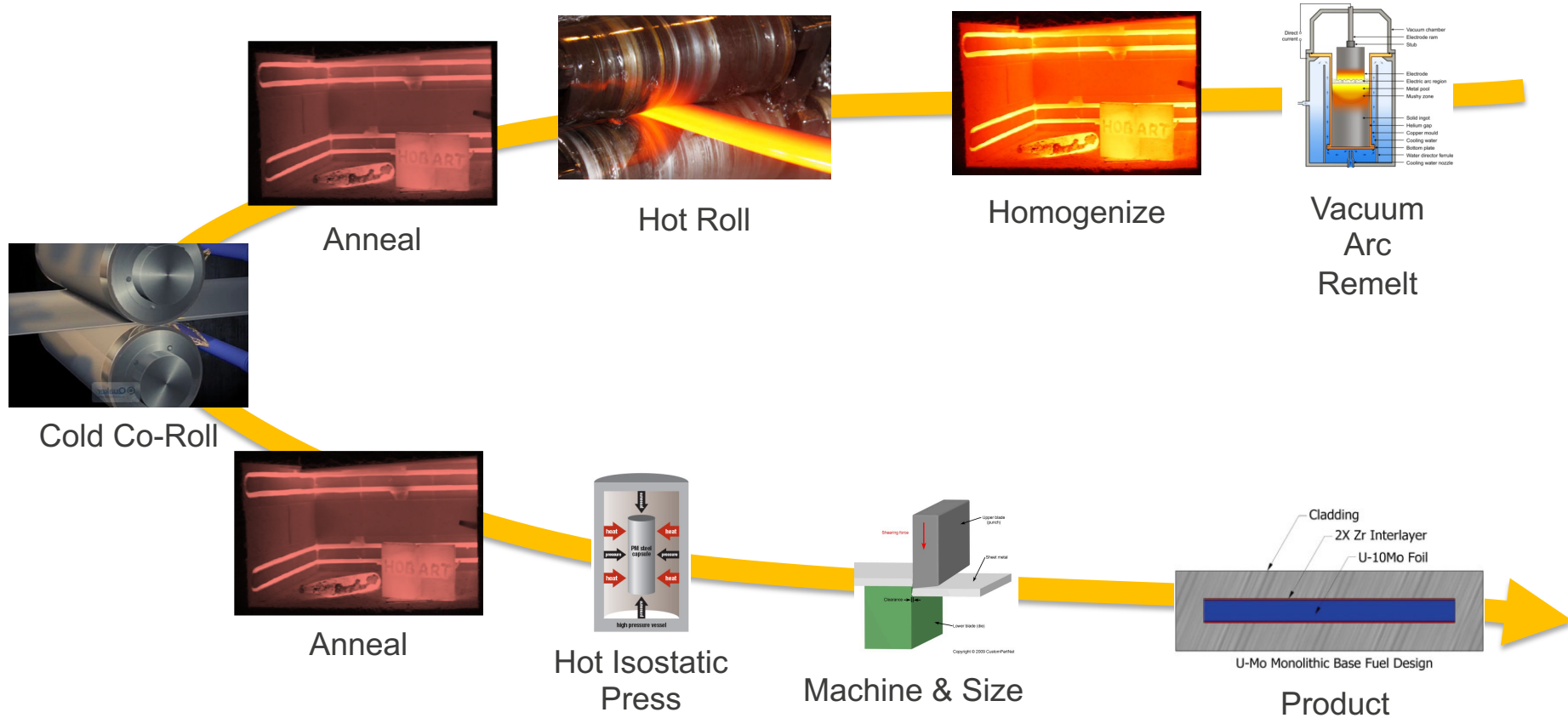
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The Mission

- **MISSION**: To develop high-density, monolithic U-Mo fuel for research reactor conversions
 - Current reactors use HEU dispersion fuels
- **Aimed at converting current research reactors to the use of non-weapons-grade low-enriched uranium (LEU) fuels.**
 - Reduce the amount and availability of weapons grade uranium
- **Both domestic and abroad, programs are converting to a monolithic LEU-10Mo fuel source**



Domestic Monolithic Fuel Fabrication



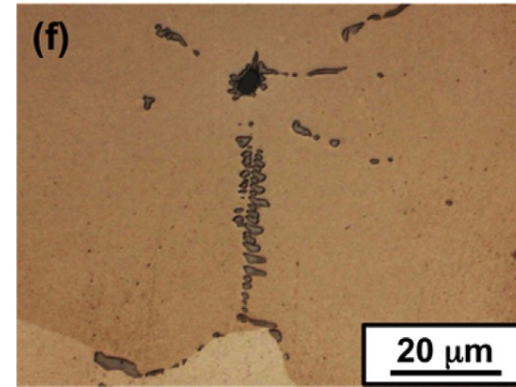
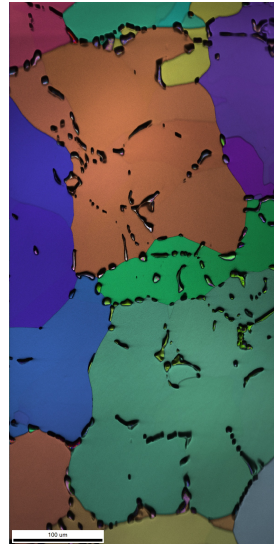
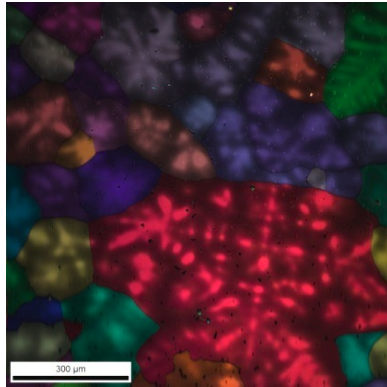
As Received Ingots, Courtesy of Y-12

- **We have:** Dimensions, Weight, and Chemistry.

Ingot ID	Sample ID	Mass (g)	richment	%U	U (g)	U-235 (g)
3K32-M4-X21F	Y143630030	1517.6	0.215	89.7	1361.29	2.93
3K32-M5-X21F	Y143630030	1617.6	0.215	89.7	1450.99	3.12

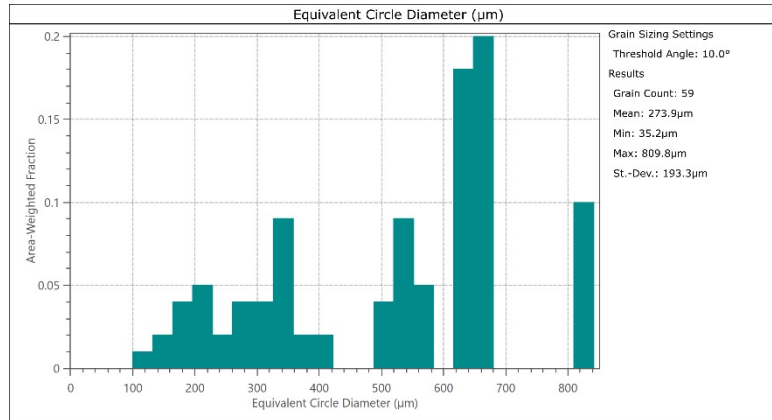
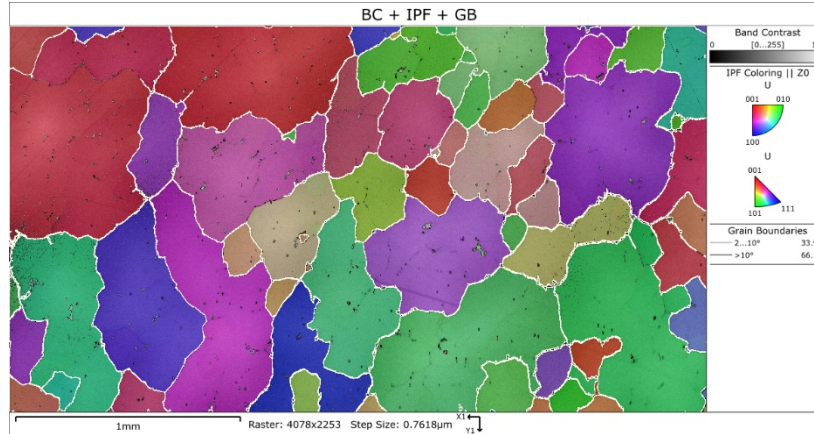
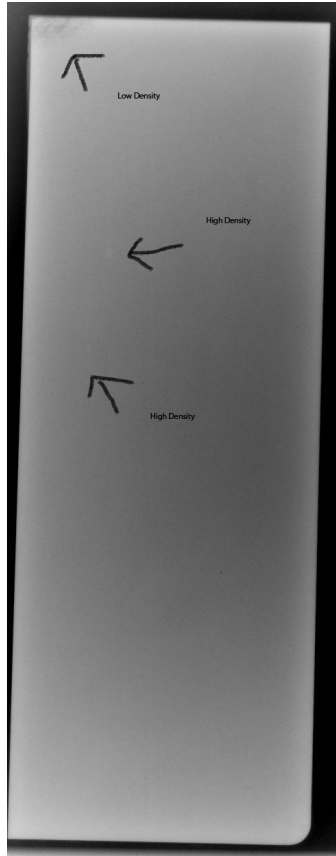
Analyte Id	Analyte Name	Result
7440440	Carbon	526
	Aliquot	524
	Aliquot	524
	Aliquot	529

- **We Need:** Radiography, Microstructure, Homogenization
 - Is the Molybdenum homogenous?

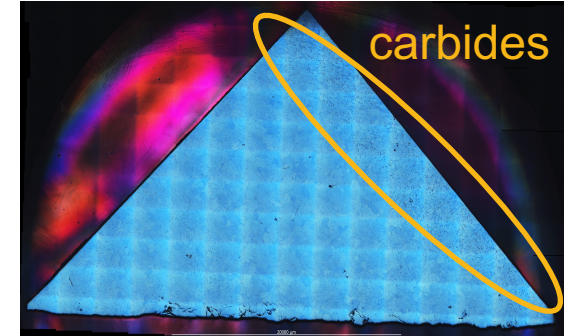


As-Received Ingots

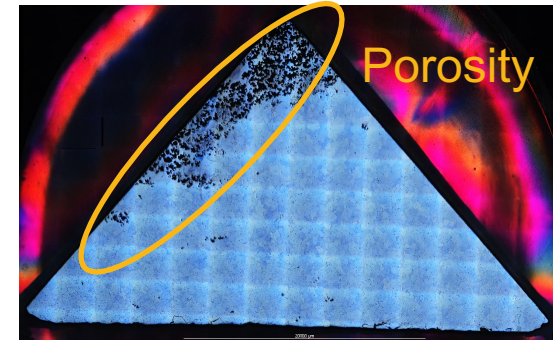
Grain size



3K32-N7-XLJP-1



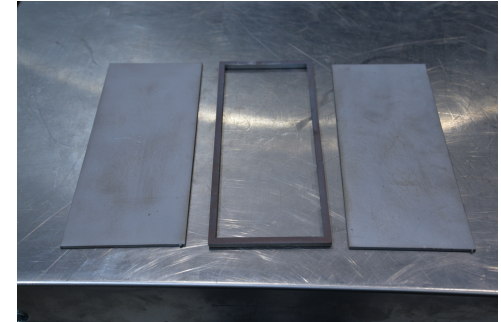
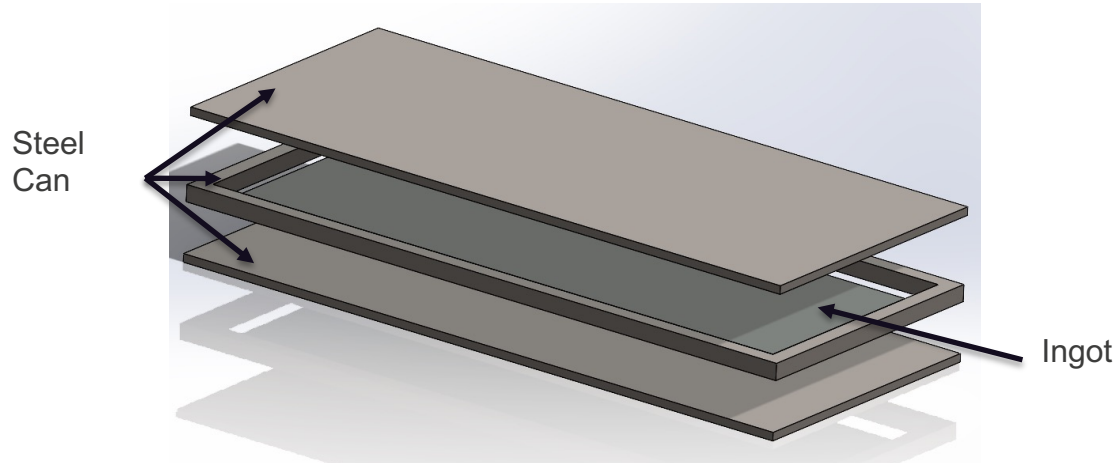
3K32-N9-XLJP-1



Hot Rolling – The Preparation

- **Hot Rolled in a Steel Can**

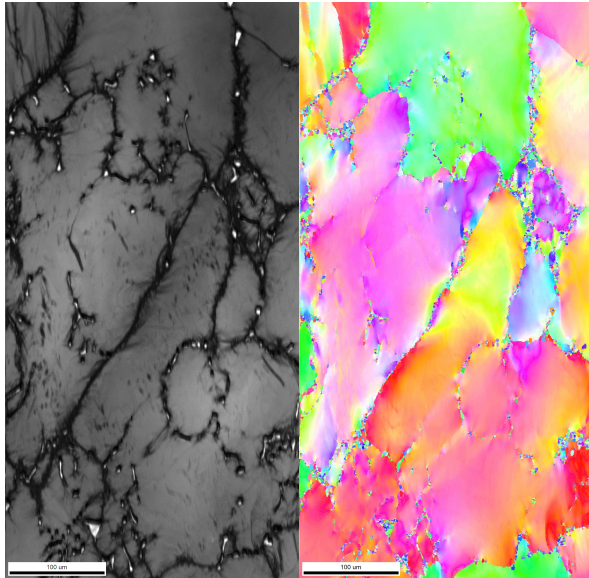
- Prevents oxidation, rad con, and improves surface quality
- Steel cans are cleaned, coated, and welded around the ingot
- Electron beam welded in vacuum



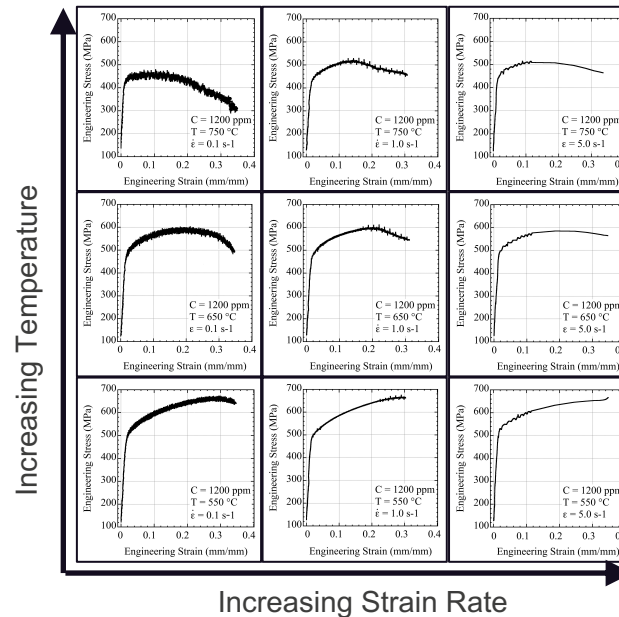
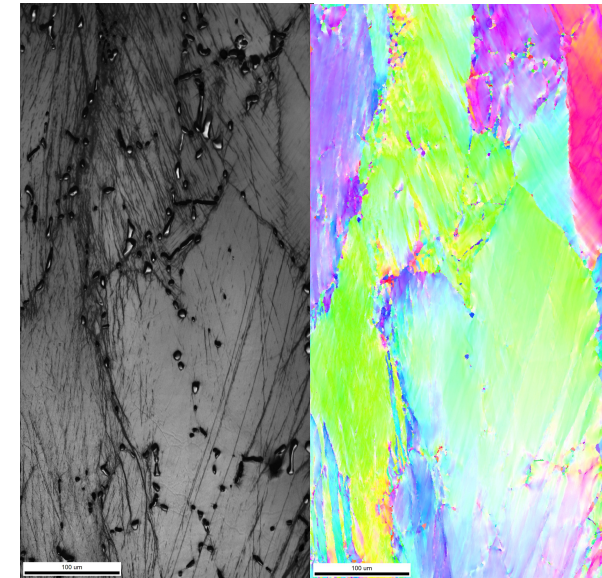
Hot Rolling – The Conditions

- Rolled at 700 °C (just below the eutectic at 725 °C)
 - Strain Rate of $\sim 0.1 \text{ s}^{-1}$
 - 10% to 12% reduction per pass = dynamic recrystallization

750 °C, 0.1 s^{-1}

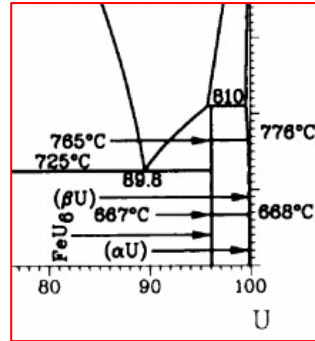
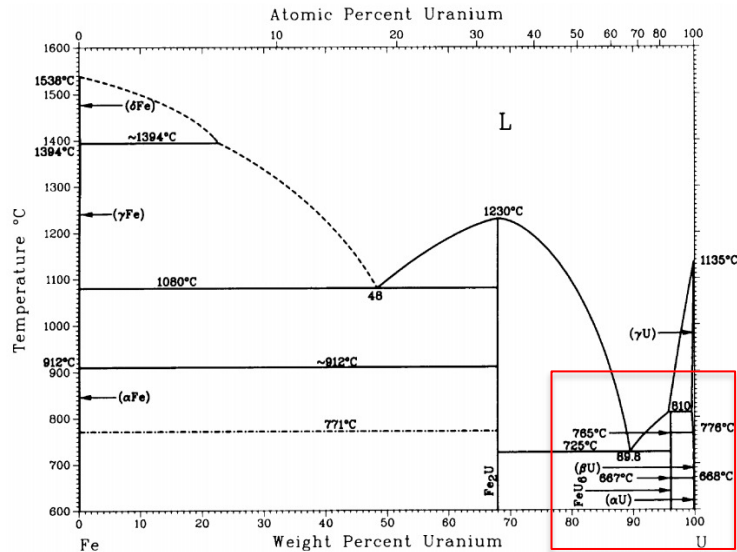


550 °C, 5.0 s^{-1}



Lessons Learned – The U-Fe Eutectic

- Furnace control and patience is key
- Too high a temperature to reduce wait time backfires



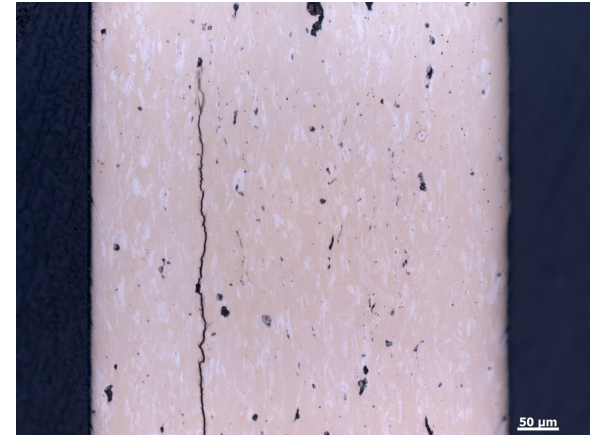
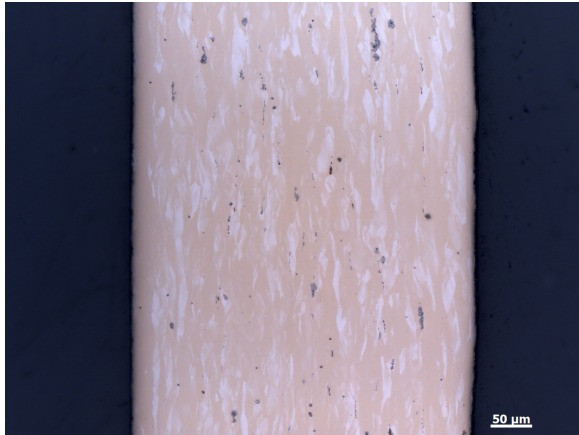
Lessons Learned - Patience

- **Too little reduction, or too cold an ingot, results in curled foils**
 - Flatten in the Nordberg = broken foil
- **Waviness in the can material isn't an issue, doesn't translate to ingot**
 - Can lid is thinning



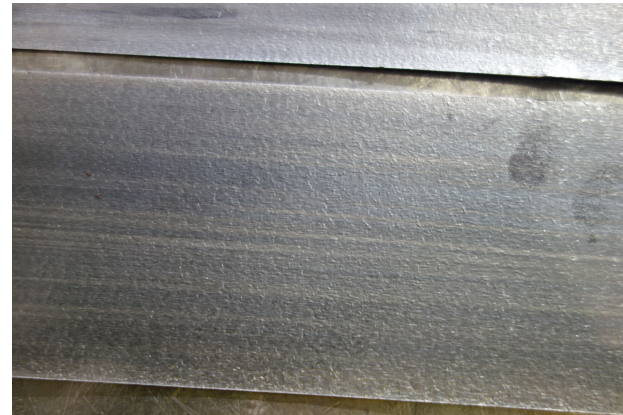
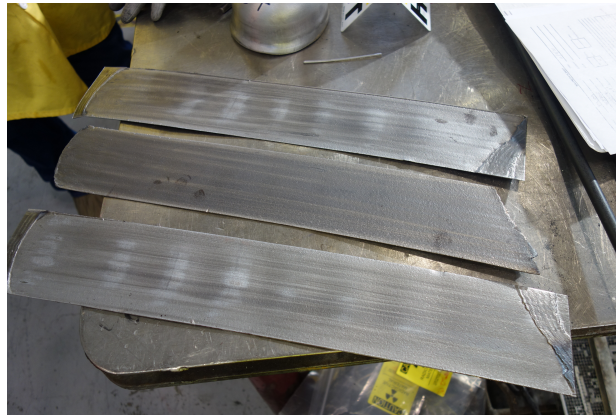
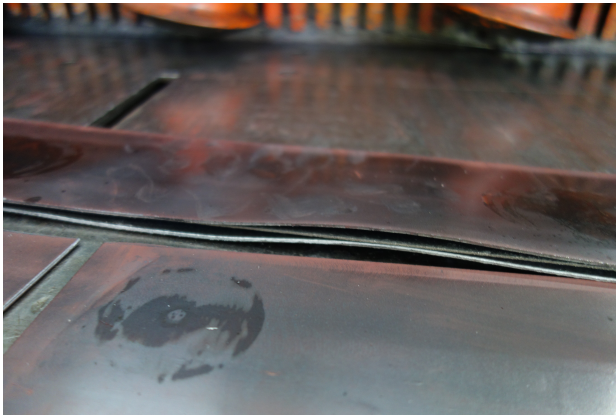
Lessons Learned – Stress Corrosion Cracking

- **SCC occurring if foils sit following hot rolling**
 - Anneal immediately following rolling or,
 - Preserve under vacuum until annealed



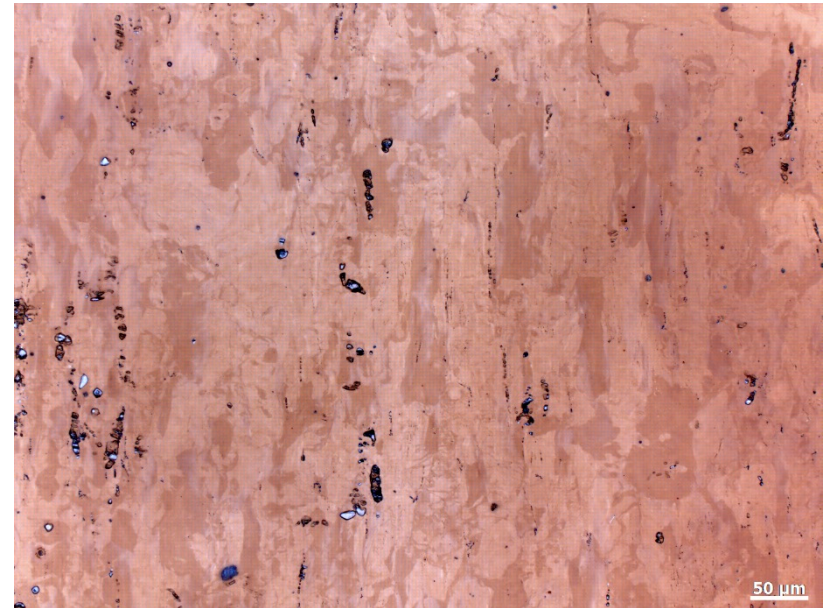
Decanning

- Can isn't perfectly straight
- We have a power shear and a dewalt handheld shear
- Don't cut the uranium!



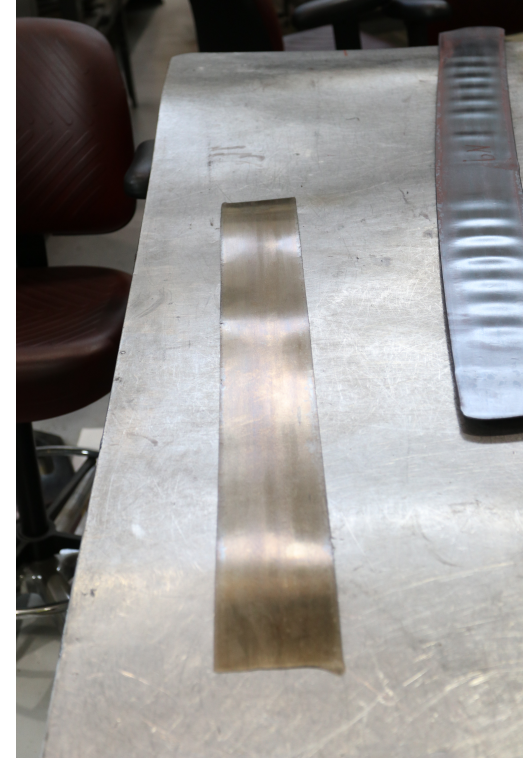
Hot Rolled + Annealed Microstructure

- **Potential Molybdenum banding?**
 - Historical concern of the CONVERT program
- **Partial recrystallization?**
 - Change anneal to 700°C-4h



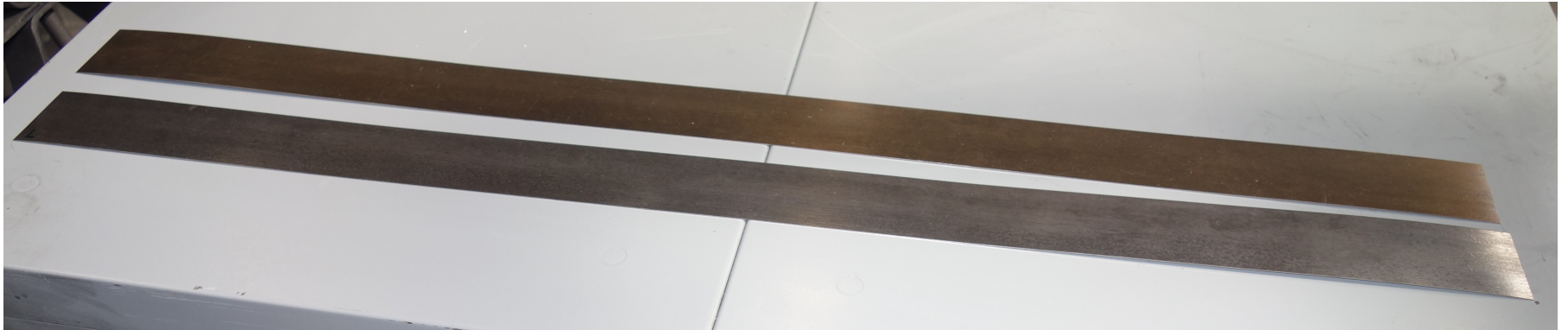
Cold Rolling

- 30+ passes in 0.001"-0.002" increments
- Most foils finish very flat and straight
- Some degree of edge cracking



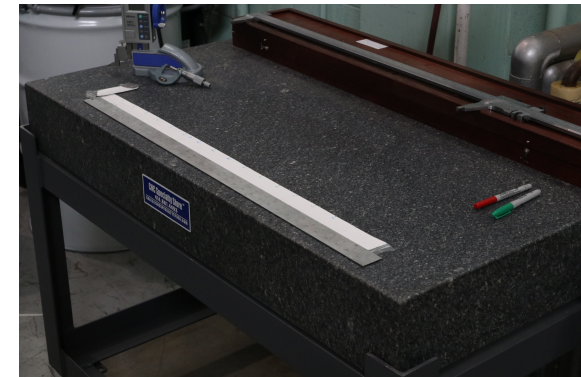
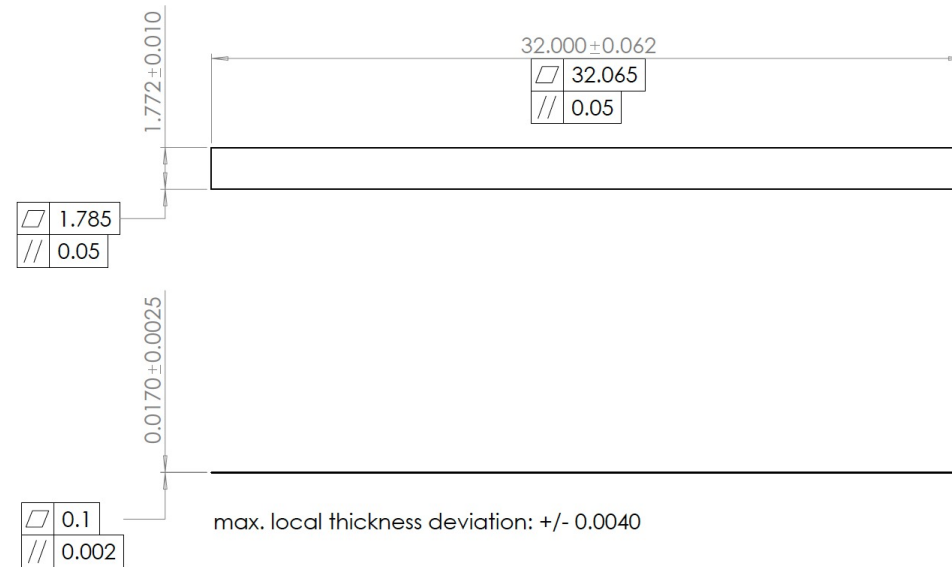
Foil Sizing

- **Sounds easy, how do you do it?**
 - EDM – Too expensive, recast layer
 - Waterjet – Too expensive, criticality concerns
 - Shear – Cheap, let's do it!
 - Slitter – Cheap, lets do it!
- **Most difficult part of the program**



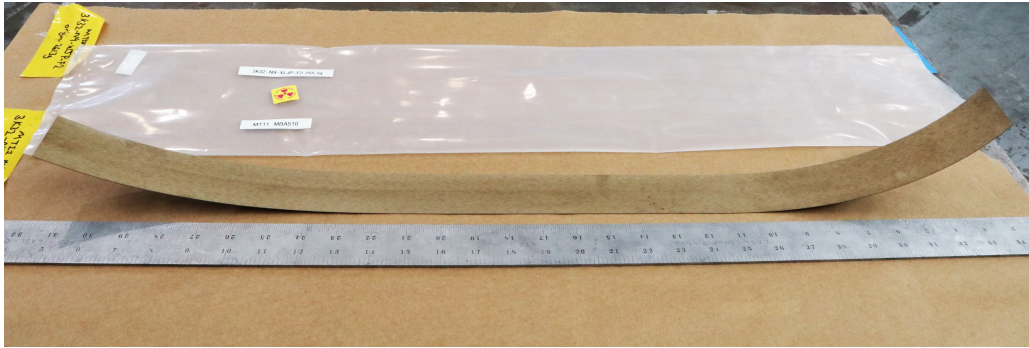
Inspection

- What does our customer want?



Inspection

- A flattening anneal following sizing has been added
– 700 °C – 1 h



Packaging

- **Moral of the story...**
 - Coordination is key!
- **How do you go from sizing, to cleaning, to inspection, to packaging, in a day.**
 - Sizing: 2 h
 - Cleaning: 2 h
 - Inspection: 3 h
 - Packaging: 4 h
- **Every step of this project takes coordination, among people, teams, equipment, availability.**

Thanks to Our Teams

- **Powder Materials Processing**
 - Erik Luther
- **Deformation Processing**
 - Carl Osborn, Ryan Mier, Allie Glover, Sean Raybon
- **Electrochemistry**
 - Don Johnson, Randy Edwards
- **Welding**
 - Stephen Weist, Andy Duffield, Brett Ireland, Mark Sandoval, Michael Strohmeyer
- **Characterization**
 - Kevin Bohn, Robert Forsyth, Eric Tegtmeier, William Winter
- **SIGMA Operations**
 - Hannah Cross, JD Montalvo, Chastity Vigil, Jonathan Zambrano
- **RCT**
 - Bryan Bonser, Daniel Romero, Greg Sharp, Sophia Winward

Thank You!